Nutritional Requirements During Training for Special Operation Forces – An Observational Study

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Research

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Abstract

Background: Responses to exercise training can vary greatly between individuals. For special operation forces, low responses to training can hamper performance. In this study, we objectively measured strength and fitness during special operation forces training, and assessed potential determinants of the training response.

Methods: Twenty subjects were enrolled, and measurements were taken before and after a 9-week training program. Muscular strength was measured as one-repetition-maximum on four instruments, and physical fitness by the Cooper-test. Body composition was measured using deuterium dilution, physical activity by accelerometry and diet quality by food records. Level of significance was $p < 0.05$.

Results: During the 9-week training period, body strength increased by 0.33 ± 0.24 N/kg (+7%, $P < 0.001$), and physical fitness increased by 3.5 ± 3.4 mL/min/kg (+6%, $P = 0.001$). Gains in strength were inversely associated with strength at baseline, and positively with activity intensity during the training program. We observed no effect of training on body weight, but body composition was significantly different at follow-up as compared to baseline ($16.9 \pm 2.5\%$ to $14.9 \pm 2.5\%$ body fat, $P = 0.03$). Energy intake was 4491 ± 506 kcal/d and energy balance was -243 ± 306 kcal/d ($P = 0.04$). Average physical activity level was 2.6 ± 0.2 and the average duration of moderate-to-vigorous physical activity was $5:53 \pm 0:36$ h. Over time, physical activity did not change significantly. After adjustment for underreporting, intakes of vitamin C and D were insufficient on average and for most participants.

Conclusions: Improvements in strength were modulated by strength prior to the intervention, and moderate-to-vigorous physical activity during the training. Thus, compensatory declines in physical activity may hamper the effectiveness of the exercise program.

Introduction

Military performance is crucially dependent on soldiers physical fitness and health. Low mass and strength of the musculoskeletal apparatus increases the risk for injuries and fatalities [1, 2]. Impaired metabolic health may negatively affect endurance, resiliency, and recovery [3, 4].

To increase physical fitness and strength, all soldiers undergo baseline training and maintain a schedule of regular exercise thereafter. Between military personnel, physical fitness requirements differ by position and requirements for special operation forces are higher as compared to other task forces. To achieve increased physical fitness, these soldiers follow another, specialized training in which training load is higher, both in duration and intensity.

Responses to exercise training can vary greatly between individuals [5]. Factors that may explain such variability may include training intensity [6], nutritional adequacy and quality [7], and compensatory changes in habitual physical activity and nutrition [6, 8]. In a relatively standardized setting of location,

training schedules, and diets, it is important to determine whether such variability in exercise response is also observed in military recruits and to identify factors that modify training effects.

To gain insight into the effect of special forces operations training and predictors of this response, we performed a study in which we assessed physical fitness and strength, as well as body composition, diet quality, and physical activity in soldiers following an 9-week training.

Methods

Aims, Design and Setting

Before and after the 9-week training program, measurements of strength, fitness, and body composition were performed. During the training period, physical activity and diet quality were assessed. During the base training, recruits spend five days a week at the military basis, performed their training and receive standard military diets. During weekends, recruits were allowed to travel, e.g. home, with no instructions for physical activity and diet.

Participants

Participation in this study was offered to recruits who were to follow the base training of the Special Forces of the Royal Dutch Army. Twenty, healthy subjects volunteered to participate in this study between March and May 2016.

10 participants completed measurements of body composition before and after training: among the 10 dropouts, Four subjects did not complete the study, two subjects left the military training program, one subject quit the study because of the experienced high load of the study and one did not perform fitness testing after the study, 5 measurements resulted in unreliable body water-estimates, and one participant did not collect the post-dose urine sample before training. Anthropometrics, strength and fitness were not different between those who completed measurements and those who did not (Table 1).

Table 1
Baseline anthropometrics and physical fitness assessments.

	N	Mean $\pm$ SD	P
Age, years	16	25.9 $\pm$ 3.6	0.95
	10	26.3 $\pm$ 4.2	0.61
Length, m	16	1.83 $\pm$ 0.05	0.28
	10	1.83 $\pm$ 0.06	0.9
BMI, kg/m ²	16	24.5 $\pm$ 1.7	0.26
	10	25.2 $\pm$ 1.4	0.2
Body Weight, kg	16	82.4 $\pm$ 7.5	0.88
	10	84.3 $\pm$ 7.6	0.27
Strength, N/kg	16	4.95 $\pm$ 0.73	0.79
	10	4.96 $\pm$ 0.73	0.88
Fitness, mL/min/kg	16	54.3 $\pm$ 2.2	0.39
	10	54.5 $\pm$ 2.5	0.92
<i>P-values refer to comparison of baselines values between participants with complete data and incomplete data at follow-up (for cohort for primary outcomes: n = 16 vs n = 4, for cohort for secondary outcomes: n = 10 vs n = 10, data of drop-outs not shown). Strength and fitness are expressed per kg body weight.</i>			

Procedures

Muscular strength

Muscular strength was measured as one-repetition-maximum on the chest press, leg press, vertical traction, and shoulder press. Strength was calculated as the sum of forces on four exercises divided by body weight.

Physical fitness

Physical fitness was assessed by the Cooper-test [9]. The Cooper-test assesses the distance participants are able to run in 12 minutes. Physical fitness is estimated as age- and sex-specific function of the achieved distance.

Body composition

Anthropometrics of the subjects were obtained at the second day and at the last day of their base training.

Body weight was measured with minimal clothing (e.g. underwear) after an overnight fast. Body composition was measured using Deuterium dilution according to the Maastricht Protocol [10]. Before the subjects went to bed, they collected a baseline urine sample. Immediately thereafter, subjects ingested 70 mL of the deuterium solution. The following day, approximately 8 hours after consuming the isotope dilution, a sample of their second morning urine was collected. In-between ingestion of the deuterium solution and collecting the second morning urine samples, the subjects were not allowed to consume anything. Total body water was calculated by the Plateau-Method, and fat-free mass was calculated as total body water divided by 0.73, assuming 73% hydration of fat-free mass. Fat mass was calculated as difference between body weight and fat-free mass.

Energy homeostasis

Energy intake was calculated from self-report by dietary records ('Reported'), and using the energy intake-balance method ('Calculated'). The intake-balance method utilizes the first law of thermodynamics, and calculates energy intake as the sum of energy expenditure and changes in body energy stores. Total energy expenditure was estimated using accelerometry. Changes in body energy stores were calculated as the difference between fat mass and fat free mass in the first and last week of the study, multiplied by their respective energy densities of 9300 kcal/kg fat mass and 1100 kcal/kg fat-free mass [11].

Dietary quality

A daily food record was used to assess dietary intake. Food records were completed by the participants every weekday and during one weekend by the participants.

During week days, food and drinks were supplied to the participants, allowing specific knowledge about their diet composition. During weekends, diets were *ad libitum*. Dietary intake was quantified as energy content, macronutrient composition (as percentage of total energy), and adequacy of micronutrient and vitamin intake (as % of the Recommended Daily Allowance) using the NEVO-table.

Physical activity

Physical activity was monitored using waist-worn accelerometers (ActiGraph GT3X, Actigraph, Pensacola, FL, USA). Physical activity was recorded during the entire training period of nine weeks. To minimize burden, every participant wore the accelerometer for 4 out of 9 weeks; one week in each period: week 1–2, week 3–4, week 5-6-7, and week 8–9. For each period, accelerometers were randomly assigned to 10 participants; the remaining 10 wore the accelerometer during the following week. Data of non-wear weeks was linearly imputed from the week before and after. Accelerometers were worn 24/7 and only detached prior to water activities, e.g. swimming, showering. The subjects wore the accelerometers only for one weekend to monitor physical activity behaviour at home.

The ActiGraph is a compact ($3.8 \times 3.7 \times 1.8$ cm) and lightweight (27 g) device that has a rechargeable lithium polymer battery. It measures acceleration in three planes: mediolateral (X), vertical (Y), and anteroposteral (Z). The sampling rate of the accelerometer was set at 30 Hz. A low frequency extension filter was used to analyze the data. The acceleration data of the three planes from each minute was used.

The vector magnitude was calculated as followed: $\sqrt{(\text{Axis } 1^2 + \text{Axis } 2^2 + \text{Axis } 3^2)}$. The Freedson Vector Magnitude 3 cut-off values were used to calculate the intensity of the physical activities per minute [12]. These cut-off values were based upon the counts per minute (CPM). The intensity ranges were: light (0-2690 CPM), moderate (2691–6166 CPM), vigorous (6167–9642 CPM), and very vigorous (> 9643 CPM).

Total energy expenditure (TEE) was calculated by converting accelerometer vector magnitude counts per minute to kilocalories per minute using the Freedson VM3 Combination formula [13]. Basal metabolic rate (BMR) as calculated from age, height and body mass using the Oxford [14] equation. The physical activity level (PAL) was calculated as TEE divided by BMR.

Statistical analysis

Results of all the parameters were expressed as mean $\pm$ SD. Normality was confirmed for all variables using Shapiro-Wilk-tests. Changes over time, e.g. body weight and composition, were analyzed using paired samples t-tests, baseline differences between subjects for secondary outcome analysis and excluded participants due to incomplete follow-up data were compared using unpaired t-tests. Dietary intakes were tested against 100% of Recommended Daily Allowances. Correlations were tested using Pearson correlations. Results were considered statistically significant if $p < 0.05$.

Results

Strength and Fitness

During the 9-week training period, body strength increased by 0.33 ± 0.24 N/kg body weight (+ 7%, $P < 0.001$, Fig. 1A). During the same period, physical fitness increased by 3.5 ± 3.4 mL/min/kg body weight (+ 6%, $P = 0.001$, Fig. 1B). The inter-individual response variability to the training program was 25% (-4% to + 19% for strength, and - 2% to + 24% for fitness). Excluding two 'hyper-responders' (fitness, + 7 and + 13 mL/min/kg), the change in fitness remains significant ($+ 2.4 \pm 1.6$ mL/min/kg, $P < 0.001$). If strength and fitness were adjusted for fat-free mass, the changes remained significant (strength: $+3 \pm 3\%$, $P = 0.007$, fitness: $+3 \pm 4\%$, $P = 0.03$).

Body weight and composition

During the 9-week training, body weight did not change (Fig. 2A). In 10 participants with body composition data at follow-up, we observed no change in body weight either, but body composition was significantly different at follow-up as compared to baseline ($16.9 \pm 2.5\%$ to $14.9 \pm 2.5\%$ body fat, $P = 0.03$, Fig. 1B). Fat mass decreased significantly (-1.8 ± 2.2 kg, $P = 0.03$), whereas fat-free mass increased, yet not statistically significant ($+ 1.2 \pm 2.0$ kg, $P = 0.09$).

Energy Balance

On average, total energy expenditure was 4773 ± 395 kcal/d (Fig. 3A), and resting metabolic rate was 1844 ± 124 kcal/d. Calculated energy intake was 4491 ± 506 kcal/d and thus, energy balance was $- 243$

± 306 kcal/d ($P = 0.04$). Participants reported energy intake of 2973 ± 443 kcal/d, which is $31 \pm 6\%$ (or -1380 ± 275 kcal/d) less than calculated.

Physical Activity

Complete activity data was only available for 13 participants. Average physical activity level was 2.6 ± 0.2 . The average duration of activity per day was $16:23 \pm 0:48$ h during weekdays, and $8:14 \pm 4:05$ h/day during weekends ($P < 0.001$ vs weekdays, Fig. 4A). Over time, total recorded activity did not change ($P = 0.54$). However, as shown in Fig. 4B, we observed decreases in moderate intensity-activities from Week 1–2 to Week 8–9 (-53 min/day, or $-1:09 \pm 1:13$ min/day/week, $P < 0.001$), and vigorous intensity-activities (-13 min/day, or $-0:22 \pm 1:00$ min/day/week, $P = 0.06$), while very vigorous intensity-activities increased over time ($+ 23$ min, or $+ 0:20 \pm 0:28$ min/day/week, $P = 0.01$).

Dietary intake

Dietary intake was composed of $45.9 \pm 3.0\%$ carbohydrates, $32.8 \pm 2.2\%$ fat, and $17.5 \pm 1.3\%$ protein. Protein intake was 2.35 ± 0.25 g/kg body weight/day.

Based on self-reported dietary intake, intakes of Vitamin B12, C, D, and salt were significantly lower than the Recommended Daily Allowances (Table 2). After adjustment (intake divided by % underreporting), only intakes of vitamin C and D were insufficient on average and for most participants.

Table 2

Diet quality as compared to recommended daily allowance during special operation forces training.

	RDA	N	Mean $\pm$ SD	N < RDA	P
Protein	1.2 g/kg	16	131 $\pm$ 18	1 (6%)	< .001
		10	192 $\pm$ 23	0 (0%)	< .001
Vitamin B12	2.8 μ g	16	68 $\pm$ 16	16 (100%)	< .001
		10	108 $\pm$ 16	3 (30%)	0.31
Vitamin C	70 mg	16	35 $\pm$ 13	16 (100%)	< .001
		10	57 $\pm$ 22	10 (100%)	< .001
Vitamin D	2.5 μ g	16	54 $\pm$ 16	16 (100%)	< .001
		10	82 $\pm$ 18	8 (80%)	0.01
Folate	300 μ g	16	93 $\pm$ 16	9 (56%)	0.11
		10	144 $\pm$ 20	0 (0%)	< .001
Salt	2000 mg	16	81 $\pm$ 14	14 (88%)	< .001
		10	123 $\pm$ 14	0 (0%)	0.002
Calcium	1000 mg	16	121 $\pm$ 33	4 (25%)	0.03
		10	196 $\pm$ 34	0 (0%)	< .001
Magnesium	300 mg	16	107 $\pm$ 15	6 (38%)	0.14
		10	162 $\pm$ 16	0 (0%)	< .001
Iron	14 mg	16	139 $\pm$ 24	1 (6%)	< .001
		10	212 $\pm$ 28	0 (0%)	< .001
Zinc	15 mg	16	107 $\pm$ 18	5 (31%)	0.14
		10	167 $\pm$ 15	0 (0%)	< .001

Data are presented as mean $\pm$ SD and as number (and percentage) of participants who did not achieve recommended daily intake allowances (RDA). Dietary intake is presented as percentage of Recommended Daily Allowances. Values are presented as reported by the participants (n = 16), and as calculated (n = 10), adjusted for underreporting. Adjustments are only available for participants with body composition-data. P-values indicate the statistical significance for the comparison to 100%.

Determinants of improvements in strength and fitness

The increase in strength during the base training was negatively associated with strength ($r = -0.62$, $p = 0.01$), and fitness ($r = -0.52$, $p = 0.04$) at baseline. Furthermore, the increase in strength during 9 weeks of training was associated with an increase in moderate ($r = 0.56$, $p = 0.03$), vigorous ($r = 0.59$, $p = 0.02$), and

very vigorous-intensity activity ($r = 0.66$, $p = 0.01$) during training. Lastly, larger gains in strength (adjusted for body weight) associated with larger energy deficits ($r = -0.66$, $p = 0.04$, $n = 10$), and losses in fat mass ($r = -0.66$, $p = 0.04$, $n = 10$), but not with changes in fat-free mass (N.S.). If strength was adjusted for fat-free mass instead of body weight, these associations disappeared. Changes in fitness were not associated with any assessed variable.

Discussion

In the present study, we report the improvements in fitness and strength observed during a 9-week special operation forces training in soldiers of the Dutch Army. This is the first study to objectively measure physical activity and activity intensity using accelerometry during the training period. Thereby, this study allows to assess whether improvements in fitness and strength are affected by the intensity of physical activity during the training period. In addition, we measured body composition and collected dietary records to determine nutritional adequacy during this high-intensity training program.

The present study demonstrates that the 9-week special operation forces training achieved the expected improvements in physical fitness and whole-body strength (+ 6–7%). Adjusting for individual changes in fat-free mass, largely composed of muscle mass, the increase in fitness and strength were small (+ 3%), but remained significant. Thus, strength and fitness improved likely as a result of increased muscle mass and quality and respiratory capacity. The inter-individual range in response to the training program was 25%. For strength, the increase negatively associated with strength prior to training, demonstrating that strong individuals benefit less from the training program. For fitness, no such association was observed and thus, the prescribed training achieves improvements in fitness even in fit individuals.

The training regimen in this observational study imposed an average physical activity level of 2.6, which is high. Inter-individual differences in physical activity during the training program, in moderate, vigorous, and very-vigorous intensities, associated positively with changes in strength. Thus, this study suggests a dose-response relationship with intense activities, but not with low-intensity activities. The training-effect on fitness was not determined by the variability in physical activity levels during the 9-week training. Of note, maintaining a physical activity level at this level for > 60 days approximates to 67% of the maximal human physical capacity, which has been estimated using studies of long-term endurance capacity, e.g. arctic trekking, ultra-marathons and mountaineering [15]. Importantly, these estimates are derived only from week-days, thus training days, and physical activity during the weekends was significantly less (~8 hours).

At the observed physical activity level, we estimated energy intake requirements during the training to be 4773 kcal/d, or ~ 60 kcal/kg body weight per day. These estimates confirm energy requirement studies using gold-standard methodology, that is doubly labeled water [7, 16, 17]. Importantly, accelerometry measures body movements and energy requirements are estimated as a function of body movements and body weight. During many activities, soldiers were required to carry additional weights, e.g. 20 kg-

backpacks, and thus physical activity levels, energy requirements and energy intakes were likely higher than reported.

While the imposed training program did not affect body weight, soldiers lost 1.8 kg of fat mass, while gaining 1.2 kg of fat-free mass. The gains in fat-free mass are comparable to other exercise training studies [18, 19]. Based on the changes in body composition, we estimated that soldiers consumed 330 kcal/d less than they expended. Energy balance was calculated based on changes in body composition and is therefore not affected by confounding by carrying additional weights. Despite being in a small energy deficit, dietary records demonstrate sufficient intake of proteins, the primary dietary driver of changes in muscle mass and strength during exercise training. In contrast to other studies [20], gains in muscle mass during an energy deficit were not associated with protein intake, which is likely because protein intake was sufficient in all individuals. The association between changes in strength and energy deficit is explained by changes in fat mass, because it is a factor in calculating energy balance and a denominator in calculating strength. If strength is adjusted for fat-free mass only, changes in strength do not associate with energy balance.

We did not observe any associations between changes in fitness or strength with diet quality, i.e. adequacy of nutrient intake. Nevertheless, after adjustment for underreporting of energy intake (~ 30%), we observed significant deficiencies in vitamin C and D intake. Although these deficiencies did not cause any adverse effects on outcomes of this study, others have shown detrimental effects of vitamin deficiencies on physical function, metabolic health and bone quality [21–23].

This study is the first to use objective measurements of physical activity during high-intensity exercise training for special forces operations. In light of the intense training, burden to the participants of this study had to be minimized, and therefore, collection of this data, and in addition of diet and body composition data, is exceptional. Due to the specialized nature and target population, it is limited in its subject size, which is small, and the burden of the study in addition to the demanding training may explain the missing data. However, the results of this study, despite preliminary in nature, are valuable to inform optimization of training strategies.

Conclusions

The present study demonstrates efficacy of training programs in special operation forces to increase physical strength and fitness. Improvements in strength, but not fitness, were modulated by strength prior to the intervention, and moderate to vigorous physical activity during the training. Compensatory declines in physical activity may hamper the effectiveness of the exercise program. Vitamin C and D intake requirements were not met and thus might require supplementation. For future studies, the use of doubly labeled water in combination with accelerometry, as well as careful individual adherence to the training regimen is advised to explore variable responses in more detail.

Declarations

Ethics Approval and consent to participate: The participants were given detailed information on the study procedures. Informed consent was obtained before the start of the study. This study was approved by the Staff Joint Health Care Division of the Dutch Ministry of Defence (“Vooropleiding2016”).

Consent for publication: N/A.

Availability of data: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authorship contributions: research concept and study design (GR, GP), literature review (GR, DF, JM), data collection (GR, GP, DF), data analysis and interpretation (GR, DF, JM), statistical analyses (JM), writing of the manuscript (DF, JM), or reviewing/editing a draft of the manuscript (all).

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Figures

Figure 1

Strength and fitness before and after 9 week training. Individual data of strength and fitness (adjusted for body weight) before and after the 9-month training program are presented (n=16).

Figure 2

Body mass and composition before and after 9-week training. Data (n=16) are presented as mean±SD, and as individual changes; participants without body composition data (n=6) marked in grey. Statistical significance is indicated as *, if P<0.05, and a trend towards significance as #, if P<0.10. BW, body weight, FM, fat mass, FFM, fat-free mass.

Figure 3

Energy expenditure, intake and balance during 9-week training. Energy Expenditure (EE) as estimated by accelerometry, energy intake by self-report (EI_{Rep}, Diet records) and by calculation (EI_{Calc}, intake-balance method), and energy Balance was calculated as difference between energy expenditure and energy intake. Statistical significance is indicated as *, if $P < 0.05$ (for comparison against 0), and as ***, if $P < 0.001$ (for comparison between estimates).

Figure 4

Physical activity during special operation forces training. Physical activity was measured by accelerometry for 5 days per observation period and for one weekend.